

Developing a Holistic Digital Competency Framework for Adolescents: A Fuzzy Delphi Study

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Abstract. Digital competence among adolescents increasingly requires more than basic operational digital skills; it also involves ethical judgement, psychosocial well-being, safety, responsible use of artificial intelligence (AI), and a supportive implementation ecosystem. This study reports the second-round Fuzzy Delphi Method (FDM) consensus analysis used to refine the Digital Education Competency Framework for Insan Sejahtera (i-Digital Sejahtera), a holistic digital education competency framework for adolescents. Eleven experts evaluated 79 proposed items organised into 19 themes and five clusters using a five-point Likert scale. Ratings were converted to triangular fuzzy numbers and analysed using the threshold value (d), expert-consensus percentage, and defuzzification score (A). The pre-specified acceptance rules were $d \leq 0.20$, expert consensus $\geq 80\%$, and $A \geq 0.50$. Overall, 76 of 79 items (96.2%) met all three criteria. Four clusters achieved complete acceptance: Foundation & Value Formation (18/18), Digital Safety & Law (9/9), Future Literacy & Competency (17/17), and Ecosystem & Implementation (9/9). The Psychosocial & Well-being cluster achieved high overall acceptance (23/26), but three items within the Risk theme which are Reward vs. Punishment, Motivation and Behavioural Control, did not reach the 80% consensus criterion (72.727%), despite acceptable d and A values. The highest defuzzification score ($A = 0.800$) was observed for cross-stakeholder collaboration, psycho-educational programmes and infrastructure strengthening. The findings provide expert-consensus evidence for a multidimensional adolescent digital competency framework that integrates values, well-being, safety, future-oriented literacy and ecosystem support.

Keywords: digital competence; digital well-being; expert consensus; Fuzzy Delphi Method; i-Digital Sejahtera; artificial intelligence, adolescents

Abbreviations: AI: Artificial Intelligence; DigComp: Digital Competence Framework for Citizens; FDM: Fuzzy Delphi Method; FGD: Focus Group Discussion; ISTE: International Society for Technology in Education; KPM: Ministry of Education Malaysia; Maqasid al-Shariah: Objectives of Islamic Law; SPICES: Spirituality, Physical, Intellectual, Character, Emotional, Social, Environmental, Creativity, Economic and Service; and UNESCO: United Nations Educational, Scientific and Cultural Organization.

INTRODUCTION

Digital transformation has expanded the competencies adolescents need to participate safely, critically and productively in education and society. Digital competence is no longer adequately represented by device operation or software proficiency alone. Contemporary frameworks combine knowledge, skills and attitudes related to information and data literacy, communication and collaboration, digital content creation, safety, well-being and problem solving [1]. Empirical evidence supports this broadened conception: systematic evidence reviews demonstrate that gains in digital skills are consistently linked to young people's online opportunities, with more varied associations observed for well-being outcomes specifically [2] and recent scoping reviews of digital-competence research confirm a rapid expansion of this literature alongside persistent inconsistencies in how the construct is operationalised and measured across adolescent and young-adult samples [3]

Extending this broader understanding of digital competence, digital citizenship scholarship similarly emphasises ethical conduct, media and information literacy, participation and respectful online behaviour [4], [5]. A recent systematic review and meta-analysis provides empirical support for this scholarship, indicating that adolescents' digital citizenship levels are significantly predicted by their internet and computer self-efficacy and that digital citizenship education results in a measurable, small-to-moderate decrease in negative online behaviour [6]. In Malaysia, the Digital Education Policy frames digital education as a system-wide agenda for developing digitally fluent learners through coordinated attention to knowledge, skills, values, infrastructure, educators, leaders and strategic partners [7].

The rapid diffusion of artificial intelligence (AI) further broadens this competency agenda. AI literacy is increasingly understood as more than knowing how to operate AI tools; it includes understanding AI, applying it appropriately, evaluating its outputs and implications, and considering ethical issues [8], [9]. A 2025 systematic review of empirical research on AI-literacy in K-12 education reveals that the expanded understanding of AI literacy is becoming increasingly prevalent in classrooms, although empirical studies on measuring and assessing AI literacy predominantly focus on cognitive aspects rather than ethical and social dimensions [10]. UNESCO's AI Competency Framework for Students positions students not simply as users of AI but as responsible and creative citizens and co-creators, organised around a human-centred mindset, ethics of AI, AI techniques and applications, and AI system design [11].

The proposed Digital Education Competency Framework for Insan Sejahtera (i-Digital Sejahtera) was developed in response to this broader view of digital education. This framework is intentionally multidimensional: it combines foundational values and character formation, psychosocial and digital well-being, safety and legal awareness, future-oriented literacy and competence, and an implementation ecosystem. The framework therefore treats digital competence as a developmental and social construct as well as a technical one. Its intended outcome is an adolescent who is knowledgeable and capable in digital environments while remaining ethical, balanced, responsible and supported by the surrounding educational and social ecosystem.

A major challenge in framework development is determining which proposed elements are sufficiently relevant, distinct and important to retain. Expert-judgement methods are particularly useful when a construct is emergent, multidimensional or not yet represented by a single accepted measurement framework. Delphi methods provide a structured process for eliciting and synthesising expert judgement, while methodological literature stresses the importance of explicit expert-selection criteria, pre-specified consensus rules and transparent reporting [12], [13], [14], [15]. The Fuzzy Delphi Method (FDM) extends this logic by representing linguistic judgements using fuzzy numbers, allowing uncertainty and gradations in expert opinion to be retained during aggregation [16], [17].

This paper reports the Round 2 FDM analysis of the i-Digital Sejahtera Framework item set. Rather than treating a high average rating as sufficient, the analysis combines three decision indicators distance among expert judgements, the proportion of experts reaching consensus, and the defuzzified importance score, while also considering qualitative comments. This combination allows the analysis to distinguish between items that are broadly endorsed and items that remain conceptually ambiguous even when their average fuzzy score is acceptable.

The study addressed four objectives:

- i. To determine expert consensus on the proposed i-Digital Sejahtera sub-themes/items.
- ii. To identify which items meet the pre-specified FDM acceptance criteria.
- iii. To establish the relative priority of accepted items using defuzzification scores.
- iv. To identify items and terminology requiring refinement before final framework validation

METHODS

Research design and Round 2 context

This study used a quantitative Fuzzy Delphi Method (FDM) consensus design to refine the proposed i-Digital Sejahtera Framework. The present article focuses on Round 2, in which experts evaluated the proposed clusters, themes and sub-themes/items after an earlier process of item formation and refinement through literature review, interviews and expert discussion. The objective of Round 2 was not to generate a new list *de novo*, but to determine whether the proposed item set had sufficient expert agreement for retention and to identify items needing conceptual refinement.

Framework Development and Expert Panel Selection

The i-Digital Sejahtera Framework was developed through a preliminary literature review, interviews, and an expert workshop held on 20 September 2025 in Selangor, Malaysia, establishing a 5-cluster, 19-theme,

and 79-item structure. A purposive sample of 11 multidisciplinary experts (E1 - E11) spanning educational technology, policy, psychology, cybersecurity, and digital regulation was selected to evaluate the framework in Round 2. Purposive panel selection prioritised domain expertise and contextual knowledge over statistical representation, aligning with established Delphi guidelines [12], [15]. All 11 experts completed Round 2 anonymously, evaluating items independently while offering qualitative feedback for conceptual refinement.

Instrument and Fuzzy Response Scale

The Round 2 evaluation instrument comprised 79 items across five higher-order clusters: Foundation & Value Formation, Psychosocial & Well-being, Digital Safety & Law, Future Literacy & Competency, and Ecosystem & Implementation. Experts scored items using a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree), which was directly mapped onto triangular fuzzy numbers (m_1 , m_2 , m_3): (0.00, 0.00, 0.20), (0.00, 0.20, 0.40), (0.20, 0.40, 0.60), (0.40, 0.60, 0.80), and (0.60, 0.80, 1.00). Open-ended feedback channels allowed panelists to suggest item clarifications, renaming, or structural repositionings without re-mapping the original fuzzy anchors.

Fuzzy Delphi Analytical Procedure

Fuzzy responses were aggregated per item by averaging the m_1 , m_2 and m_3 values across experts. Individual expert variance from the group fuzzy mean was calculated using vertex distance:

$$d(m,n) = \sqrt{\{[(m_1-n_1)^2 + (m_2-n_2)^2 + (m_3-n_3)^2] / 3\}}$$

Defuzzification scores were computed via $A = \{m_1 + m_2 + m_3\} / 3$ to establish item rankings. Items were accepted if they satisfied three a priori decision criteria: threshold distance $d < 0.20$ [17], defuzzification score $A > 0.50$ [18], and a strict expert consensus rate of $> 80\%$, deliberately exceeding the standard 75% threshold to ensure high analytical rigor [14].

RESULTS AND DISCUSSION

Overall expert consensus across five clusters, 76 of 79 proposed items met all Fuzzy Delphi Method (FDM) criteria, yielding an overall 96.2% acceptance rate ($d < 0.20$, $A > 0.50$). Four clusters namely Foundation & Value Formation (18/18), Digital Safety & Law (9/9), Future Literacy & Competency (17/17) and Ecosystem & Implementation (9/9) achieved 100% item acceptance. The remaining cluster, Psychosocial & Well-being, retained 23 of 26 items; the three unaccepted items failed solely on the pre-specified 80% consensus threshold (72.73%).

Consensus at theme level expert agreement was broad, with 18 of 19 themes achieving complete item acceptance. The only exception was the Risk theme, where all three proposed items required refinement. The highest-scoring themes were Synergy & Collaboration and Digital Competency Initiatives ($A = 0.800$), followed closely by Resilience and Assessment & Curriculum ($A = 0.782$).

Highest priority items shown the highest defuzzification score ($A = 0.800$; 100% consensus; $d = 0.000$) was achieved by three items in Ecosystem & Implementation: cross-stakeholder collaboration, simulation-based psycho-educational programmes, and infrastructure strengthening. The second-highest priority tier ($A = 0.782$) spanned empathy, integrity, religious values, emotional resilience, self-control, and curriculum integration, highlighting balanced priorities across values, well-being, and systemic execution.

The three items flagged for refinement were Reward vs. Punishment, Motivation, and Behavioral Control. Although all met acceptable fuzzy score ($A = 0.673$) and threshold distance ($d = 0.162 - 0.185$) benchmarks, their 72.73% consensus rate fell short of the study's strict 80% cut-off.

Finally, Qualitative Expert Comments and Terminology Refinement as listed below:-

Qualitative feedback across 32 items revealed five primary operational refinements:

- Differentiating Self-Regulation: Resolving conceptual overlap between self-control, self-regulation, and self-discipline.
- Clarifying Definitions: Better defining broad constructs like Adaptation, Differentiated Instruction, and IT Vocabulary.
- Modernising Terminology: Updating digital hygiene concepts (e.g., renaming Password Updates to Password Protection).
- Distinguishing Ethical Boundaries: Clarifying overlaps between Politeness and Polite Communication and defining measurable indicators for moral digital messaging.
- Reframing AI Literacy: Adjusting Reliance on AI Applications to reflect the critical, wise use of AI rather than non-use.

Discussion

The Round 2 Fuzzy Delphi Method (FDM) findings demonstrate strong expert consensus for the i-Digital Sejahtera Framework, yielding a 96.2% overall item acceptance rate ($d = 0.185$, $A = 0.673 - 0.800$). Complete endorsement of the Foundation, Safety, and Future Literacy clusters underscores that adolescent digital competence requires foundational ethics, values, and critical AI engagement alongside functional skills, aligning with international AI and digital citizenship frameworks [8],[11]. High consensus on critical AI use addresses growing concerns regarding uncritical AI reliance and cognitive offloading [19]. The three items flagged for refinement within the Psychosocial cluster were not rejected for lack of importance, but to resolve conceptual overlap between external behavioural levers and internal self-regulation [20], [21], leading to their consolidation into Digital Self-Regulation and Motivation Governance. Systemic and methodological results further reinforce the framework's holistic design. The Ecosystem & Implementation cluster received the highest overall endorsement ($A = 0.800$, 100% consensus), demonstrating that individual digital competence is inseparable from supportive educational, family, and policy environments [7] and confirming the framework's nature as an ecological model [22]. Methodologically, applying a strict 80% consensus threshold validated the analytical rigor of combining multiple FDM decision criteria over mean scores alone [14], [15]. The unaccepted risk items (72.7%) would have failed even under a conventional 75% benchmark, confirming that item refinement was driven by substantive conceptual boundaries rather than an artificially high threshold.

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CONCLUSION

The FDM Round 2 analysis provides strong expert-consensus support for the i-Digital Sejahtera Framework as a holistic model of adolescent digital education competence. Seventy-six of 79 items met the combined criteria of $d \leq 0.20$, consensus $\geq 80\%$ and $A \geq 0.50$. Complete acceptance of four clusters and strong acceptance of the psychosocial cluster indicate that experts endorsed a framework extending beyond technical proficiency to include values, character, psychosocial well-being, digital safety and law, AI and future literacy, curriculum integration, leadership and ecosystem support.

The three items requiring refinement were concentrated in the Risk theme and reflected conceptual-fit concerns rather than low fuzzy importance. Together with the qualitative comments, this finding shows the value of using FDM not merely as an item-retention algorithm but as a structured refinement process. With clearer operational definitions, resolution of overlapping self-regulation constructs and updated terminology around digital hygiene and AI use, i-Digital Sejahtera Framework can proceed to final validation as a contextually grounded framework for developing knowledgeable, ethical, balanced and responsible adolescents in digital environments.

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